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Heterogeneous Deployment to Meet Traffic Demand in a Realistic LTE Urban Scenario

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***Abstract* —The main objective of the paper is to investigate and compare the downlink performance of different LTE heterogeneous network (HetNet) deployment solutions. By adding small cells to the existing macro overlay, network coverage and capacity can be significantly enhanced to accommodate the fast growth of mobile broadband traffic. Emphasis is put on how to optimally assign the spectrum for the different networks layers in an evolved HetNet including outdoor and indoor small cells. The study is conducted for a "Hot-Zone" scenario, i.e. a high-traffic area within a realistic dense urban deployment. A broadband traffic volume growth by a factor of 50 compared to today's levels is assumed. The investigated deployment schemes are outdoor pico-only, indoor femto-only and joint pico-femto deployments, all combined with an overlay macro layer. The results indicate that the best network coverage performance with a minimum user data rate of 1 Mbps is achieved when deploying small cells on dedicated channels rather than co-channel deployment. Furthermore, the joint pico and femto deployment turns out to be the right trade-off between increased base station density and enhanced network capacity.**

I. Introduction

The plethora of connected devices, such as attractive smartphones, data dongles and 3G built-in tablet computers, has brought mobile operators to face increasing demand in mobile broadband traffic and services. In addition to complementing the existing 3G network with LTE deployment, denser network deployment will play a key role in guaranteeing ubiquitous connectivity and high data speeds for the years to come. A promising and cost-effective deployment paradigm consists of mixing the overlaying macro layer with low-powered nodes, as shown in Fig.1. In such a deployment, which is denoted as heterogeneous deployment [1], the macro layer is expected to provide wider coverage but lower average data speeds; the small cells, instead, are targeted at extending network coverage and improving network capacity in traffic hot-spot areas.

In this paper, two different types of small cells will be addressed: the first one is given by outdoor pico cells, which are typically deployed at street level below rooftop, and the second one Open Subscriber Group (OSG) femto cells, i.e. any user of a given operator network can connect to femtos without any access restriction. Similarly to WiFi access points, femto cells can be installed in homes and office areas, where residential/enterprise broadband fixed connection can be directly utilized as backhaul towards the core network. In recent years, a large number of research papers have addressed femto offloading gains [2] and the performance of advanced interference cancellation techniques for co-channel pico deployment [3] in 3GPP-based statistical scenarios. A step further has been taken in [4] as the authors compare macro densification, outdoor pico deployment and also OSG femto deployment. The analysis is however valid for regular network scenarios only.

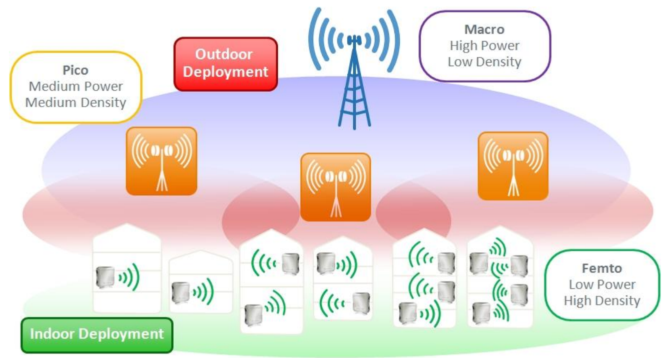

Figure 1. Overview of a multi-layer deployment scenario including outdoor macro and pico cells together with femto indoor deployment.

The focus of this paper is to investigate and compare the downlink performance of pico-only, OSG femto-only and also joint pico-femto heterogeneous deployment solutions. This is carried out in a realistic metropolitan deployment scenario, where the existing 3G macro site locations are used to co-locate the LTE sites. Realistic three-dimensional building maps are utilized to model the indoor traffic distribution, and raytracing is used to provide three-dimensional propagation characteristics. By considering a realistic case for LTE spectrum availability, the main target of the study is to determine the best spectrum allocation schemes in terms of network performance, having considered the different heterogeneous deployment solutions. Although not in the scope of this paper, the main findings can be complemented with a detailed cost analysis of the different deployment alternatives. The paper is outlined as follows: Section II describes the overall network modeling framework, Section III presents the performance modeling and simulation cases, Section IV shows the simulation results and finally the concluding remarks are found in Section V.

II. Heterogeneous Network Scenario

A. *Reference Macro Deployment Scenario Description*

This study has been carried out within a dense metropolitan scenario located in a European city. The investigated area can be regarded as "Hot-Zone, i.e. an area with intensive mobile data usage. The area size is 1.27 km^2, containing 4 three-sector 3G macro sites with optimized antenna down-tilt and average minimum inter-site distance (ISD) of 340 m. The existing 3G site locations are considered as LTE site locations to simulate the LTE macro cellular performance. In addition, interfering cells from base stations located outside the examined area are taken into account to avoid border effects. Each sector is assumed to be configured with up to 2 carriers, operating on the 800 MHz and 2600 MHz band respectively. In order to thoroughly model indoor deployment and traffic distributions, a 3D building map of the investigated area has been used, and it can be noted that 36 % of the overall area is covered by indoor locations. The total number of buildings is 915, with on average 4 floors per building, spanning from 2 to 15 floors. The average area size per building is in the order of 500 m^2.

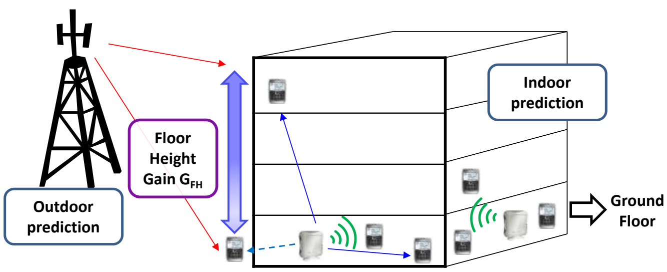

Figure 2. 3D multi-storey building model including user distribution across the floors and floor height gain for Macro path loss at higher floors.

The offered traffic load is simulated in terms of the number of simultaneous active users that are generated in the area according to a spatial user density map. A preliminary user density map has been derived with a resolution of 50 m x 50 m from extensive traffic measurement campaigns under busy hour traffic conditions. In addition to the user distribution over the entire area, indoor and outdoor traffic distribution is specified as follows: 70% of the traffic is assumed to be generated from indoor area and the remaining 30% from outdoor area. Moreover, the indoor traffic density can be further distributed amongst the various floors of the buildings, as shown in Fig.2. Considering that ground floors are usually commercial spaces that generate more traffic than higher floors, 50 % of the indoor active users are assumed to be located at the ground floor whilst the remaining part will be equally distributed amongst the upper floors.

B. *Propagation Models*

To accurately estimate link budgets, a 3D ray-tracing tool is used to evaluate path loss and antenna pattern effects with regard to the radio link between outdoor cells - macro and pico - and outdoor users. Such a tool models the radio propagation at street level by considering realistic positions and heights of the buildings that are imported from the 3D building map. Given the outdoor path loss predictions from ray-tracing tool, the indoor penetration loss within the building is calculated, for both macro and pico cells, through an additional loss (in dB) equal to $0.6 \cdot d_i + L_{extwall}$, where d_i is the distance (in meters) from the indoor location to the external wall observing the highest received signal strength, and $L_{extwall}$ defines the penetration loss through the external wall (set at 20 dB). The path loss predictions are available at a height of 1.5 m, and the received signal strength at the higher floors is modeled by applying a floor height gain of 3.4 dB/floor [5] (see Fig.2.). The model is valid for transmitters deployed above rooftop and therefore it is only applied to the macro cells. With regard to indoor femto cells, a statistical model based on [6] is considered, and it is defined as follows:

$$\mathrm{PL_{ind}(dB)} = \max(38.46 + 20\log_{10}(\mathrm{R}), 15.3 + 37.6\log_{10}(\mathrm{R}))\ldots \\ \ldots + 0.6 \cdot \mathrm{d_{2D,ind}} + 18.3n^{((n+1)/(n+1)-046)} + \sum_{\mathrm{i}} \mathrm{L_{ow,i}} \quad (1)$$

where R is the total distance in meters between the femto cell and a user (indoor or outdoor), $d_{2D,ind}$ is the distance covered inside the buildings and $L_{ow,i}$ is a penetration loss of 20 dB due to each penetrated external building wall. The penetration loss across different floors is also taken into account and depends on the number n of penetrated floors. Shadowing is not modeled for both outdoor and indoor base stations to improve simulation speed.

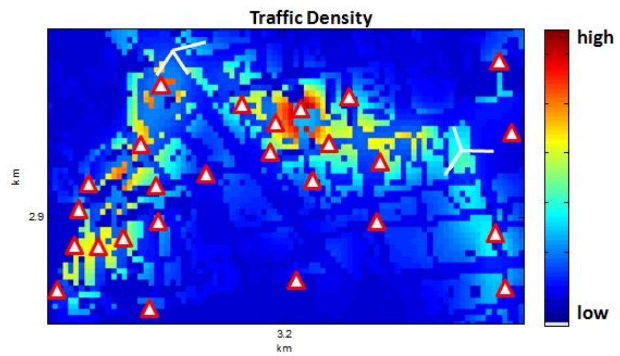

Figure 3. Overview of outdoor pico(Δ) deployment over traffic spatial distribution with 70/30 indoor to outdoor traffic split.

C. *Small Cell Deployment Strategies*

When deploying new pico and femto cells, the main goal is to find the deployment locations such that the overall downlink network outage, i.e. the percentage of users that experience a data rate below a predefined minimum required, is decreased. Two different deployment strategies have been used for picos and femtos respectively on the basis of the different transmission power and deployment constraints.

Pico cells are only deployed outdoor according to the SMART algorithm, the details of which can be found in [7]. The algorithm is made up of two steps: the first is a fast non-iterative algorithm that selects the first set of locations based on network outage spatial information; given the initial set of positions, the second step consists of a meta-heuristic algorithm that iteratively shifts the positions of the new pico cells to new locations in the study area. In the meta-heuristic search, the network performance is re-simulated for each iteration, and the algorithm ends when the best network outage is achieved or the maximum number of iterations is exceeded. Fig.3 illustrates an example of pico deployment in the investigated area, and it can be seen that the new pico cells are deployed along the streets adjacent to the buildings located in the high traffic areas.

Due to the expected high number of femto cells involved, the femto deployment strategy is based on a simpler traffic-driven deployment algorithm [8]. The main idea is that of subdividing the investigated area into spatial grids, sorting the aggregate traffic density of each grid, and finally deploying femtos in the highest traffic density grids. Femtos are deployed only at indoor locations and only at the ground floor of the corresponding buildings. The ground floor only deployment approach has been chosen because 50 % of the indoor users are assumed to be located at the ground floor. In fact, spreading the femtos over several buildings makes it possible to improve coverage and increase the number of offloaded users. Moreover, the macro signal is stronger at the upper floors and this would penalize femtos in those locations, especially for highly interfered co-channel deployment.

TABLE I. SIMULATION MAIN PARAMETERS

Cellular Layout	Realistic European deployment scenario
LTE system	Downlink FDD LTE – 2x2 MIMO
Path Loss model	Ray traced path loss for macro and pico cells Modified version of [6] for femtos Shadowing not modeled
Traffic assumptions	558 simultaneously active users Full Buffer, with 1 Mbps as required data rate.
User Distribution	Realistic user density map (see Section II) 70/30 indoor to outdoor user split 50 % of indoor users located at the ground floor
Tx Power	Macro: 46 dBm. Pico: 30 dBm, Femto: 20 dBm (DL power calibration disabled)
Antenna configuration	Macro: Real antenna pattern with down-tilt angles Pico: 6 dBi real omni-antenna , antenna height 5 m Femto: 5 dBi ideal omni antenna
Deployment Setting	Pico: Outage-driven, minimum ISD 40 m OSG Femto: Traffic-driven, minimum ISD 20 m

III. PERFORMANCE MODELING AND SIMULATION SETUP

The previously described network modeling framework has been implemented in a Matlab-based network planning tool including a static network simulator [7-9]. The main simulation parameters are defined and listed in Table I. As for the radio resource allocation, each cell performs a resource allocation algorithm [9] that is composed of two phases: in the first phase, the available resources are allocated in such a way that, if possible, each user is ensured the predefined minimum required data rate. The resources are first allocated to the users with high Signal-to-Noise Ratio (SINR) as they require the least amount of resources to get the required data rate. If additional resources are available, these are distributed to each user in a round-robin fashion. Similarly to [9], the performance indicators are obtained by means of a SINR-to-throughput mapping curve, which includes adaptive modulation and coding (AMC), HARQ and MIMO transmission up to 2x2 spatial multiplexing. The user cell selection is performed on a best-SINR basis across all the available carriers. When femto and pico cells are deployed on dedicated channel with respect to the macro overlay, an SINR bias of 3 dB is applied to the small cells during the cell-selection phase in order to extend their range and offload more users. Moreover, if macro sectors are deployed with multiple carriers, e.g. 800 MHz and 2.6 GHz, macro users are distributed amongst the multiple carriers by prioritizing the carrier with a larger product of experienced user SINR and available radio resources. In other words, users tend to connect to carriers with higher SINR and larger bandwidth. The carrier aggregation is not modeled, i.e. users only connect to one carrier at a time. Moreover, advanced traffic steering amongst the deployment layers, enhanced interference cancellation schemes and adaptive femto downlink power control are not considered in this study.

The investigated heterogeneous deployment scenarios are presented in Table II. The assumed spectrum availability refers to a typical LTE deployment in a European country, including both 800 MHz (10 MHz) and 2.6 GHz (20 MHz) spectra. The small cells are only deployed at 2.6 GHz according to two different spectrum allocation schemes: the *co-channel* case presents the full frequency reuse over the 20 MHz bandwidth between macro and small cells for both pico and femto-only deployment; in the *out-band* case, or alternatively *dedicated channel* deployment, macro and femto/pico cells transmit on adjacent dedicated channels with a transmission bandwidth of 10 MHz. When femtos and picos are jointly deployed, macro cells do not transmit at 2.6 GHz, and the overall bandwidth is utilized only by picos and femtos for both co-channel and orthogonal allocation deployment. The offered traffic load is defined as the number of simultaneous active users with a minimum data rate of 1 Mbps. Based on measured 3G data traffic load over the investigated area, a 50-fold traffic growth from today's levels can be translated into an offered traffic load of more than 500 simultaneously active users to be served in the considered area [10].

TABLE II. SIMULATED SPECTRUM ALLOCATION SCHEMES

Deployment Option	800 MHz 10 MHz	(I) 2.6 GHz, 20 MHz ***Co-Channel***	(II) 2.6 GHz, 20 MHz ***Out-band***	
Only Pico	Macro	Macro Pico	Macro 10 MHz	Pico 10 MHz
Only Femto	Macro	Macro Femto	Macro	Femto
Joint Femto-Pico	Macro	Pico Femto	Pico	Femto

IV. RESULTS DESCRIPTION AND ANALYSIS

In this section simulation results for the cases highlighted in Table II are presented. The main goal is to explore the downlink performance of deploying small cells and investigate the most advantageous carrier allocation scheme. The key performance indicator is the downlink *network outage*, which is denoted as the percentage of users whose experienced throughput is below 1 Mbps. The targeted outage value after deploying new small cells is set at 10 %. The section is divided in four subsections: subsections A, B and C present pico-only, femto-only and joint pico-femto deployment results respectively. In the last sub-section the overall best deployment options are compared in terms of average user throughput.

A. Pico-Only Deployment

Fig.4 illustrates the network outage over a different number of deployed picos together with the percentage of offloaded users to picos for both co-channel and out-band deployment. The outage values are shown by considering the split between outage users connected to the picos and those connected to the macro cells. When picos are not deployed, the macro-only deployment operating at both 800 MHz and 2.6 GHz (Dual-Band configuration) gives a network outage of 43 %, well above the

10 %-target. By increasing the number of picos it can be seen that network outage goes down for both co-channel and out-band configurations as users are offloaded to the pico cells and more capacity is available at the macro layer. When the macro and pico layers are interfering with each other, the pico cell coverage is reduced, and a lower number of users can be offloaded as compared to the out-band case. Due to increased interference on the 2.6 GHz carrier, macro users tend to be assigned to the 800 MHz - the "escape carrier" - because of higher experienced SINR. Yet, the lower bandwidth and the higher load at 800 MHz leave the macro layer congested, and the outage does not reduce below 15 % even if 40 co-channel picos (more than 3 picos per macro sector) are deployed.

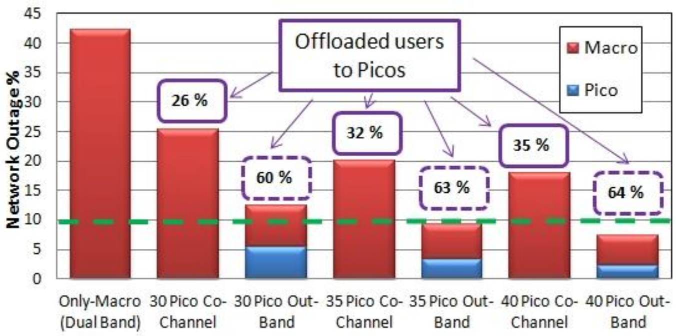

Figure 4. Network outage at 1 Mbps over different number of deployed picos for both co-channel and out-band deployment options. The percentage of users that are offloaded to picos is shown in the text boxes.

When out-band picos are deployed, it can be noted that the network outage is reduced significantly, and 35 picos, i.e. approximately 3 picos per macro sector, are sufficient to fulfill the outage requirement. The absence of interference generated by macro cells and the use of the 3 dB SINR offset for cell selection allow the pico cells to extend their coverage area. The number of offloaded users to the pico layer is doubled in comparison with the co-channel case. Moreover, the higher load at the pico layer is paid in terms of increased pico outage as the 10 MHz bandwidth does not suffice to guarantee the minimum data rate for each connected user.

B. *Femto-Only Deployment*

In Fig.5 the network outage performance is presented for femto-only deployment. In this case, the network outage is illustrated by dividing the overall outage between indoor and outdoor users. With the assumption of no cooperation amongst the different layers and no power control, similarly to pico-only deployment, a highly dense co-channel deployment does not give significant outage improvements, and 1000 co-channel femtos (787 femto/km^2) can reduce the network outage slightly below 20 % only. In the co-channel case, femto coverage is strictly confined not only within the building area, but also at the ground floor as the interference generated by macro cells is stronger at the higher floors. The percentage of offloaded users towards co-channel deployed femtos does not exceed 40 %, and this amount is not sufficient to free up resources at the macro layer. It can also be noted that with co-channel femto deployment, outdoor outage constitutes around half the overall outage level. This is due to the fact that almost all outdoor users are served by macro cells that do not have enough capacity to serve all the connected users. Moreover, doubling the number of co-channel femtos does not yield significant gains in terms of femto user intake. In fact, the high density femto deployment increases the level of interference on the 2.6 GHz band, and as a consequence of the relative SINR impairment, users tend to overload the macro escaper carrier.

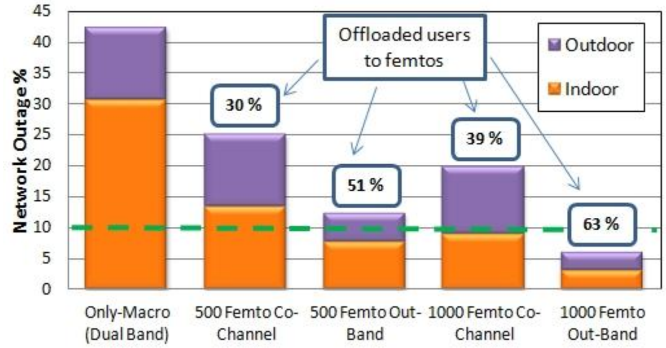

Figure 5. Network outage at 1 Mbps over different number of deployed femtos for both co-channel and out-band deployment options. The percentage of users that are offloaded to femtos is shown in the text boxes.´

When macros and femtos are deployed on dedicated channels at 2.6 GHz, femto coverage inside the buildings is enlarged, and also outdoor users in close proximity of the buildings can be served by the closest indoor femto cells. Outdoor outage is significantly reduced, but with 500 femtos, most of the network outage is still caused by indoor users that connect to the macro layer. With 1000 femtos, the number of offloaded users is of the same magnitude as the one obtained with out-band pico deployment. The 10% outage level is reached with around 500 femtos, or 393 femtos/km^2. Indeed, differently from pico deployment, the outage level associated with the femto layer is below 1 % for both co-channel and dedicated channel deployment. This is due to the fact that the number of femto served users is lower than the one experienced by pico cells and the allocated bandwidths are large enough to fulfill the minimum user throughput requirement.

C. *Joint Pico-Femto Deployment*

The network outage performance for joint pico and femto deployment is shown in Fig.6. In this case, the performance gap between co-channel and out-band deployments is smaller when compared with pico-only and femto-only scenarios. As the macro layer is deployed only at 800 MHz (see Table II) without interfering with the small cells, more than 50 % of the users can be offloaded to femtos and picos for all the configurations proposed in Fig.6. In addition, mutual interference between femtos and picos does not significantly affect the number of users connected to small cells. In order to reach the 10% outage level, 40 picos are to be complemented with 500 femtos with co-channel deployment, but the number of required femtos can be further reduced to 300 if picos and femtos transmit on dedicated channels. In the latter case, a larger percentage of users - 46 % - connect to picos, especially from the outdoor areas, thanks to reduced interference from the femto layer. As the overall number of offloaded users is split between femtos and picos, the user load per pico is lower than in the pico-only scenario, and user outage is almost totally caused by the macro layer. However, it is important to point out that in this hybrid pico-femto scenario, the outage target can be easily fulfilled without the necessity of deploying the macro carrier at 2.6 GHz.

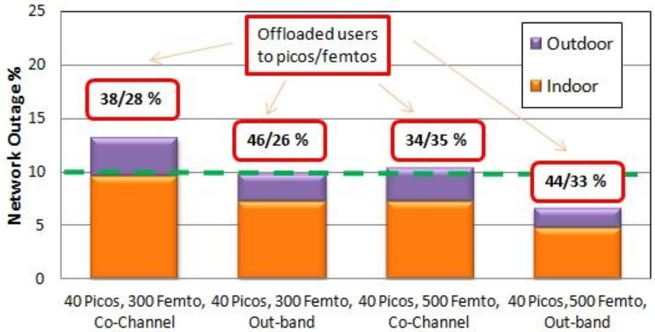

Figure 6. Network outage at 1 Mbps over number of jointly deployed picos and femtos with overlapping and orthogonal spectrum allocation. The number of offloaded users for both picos and femtos is shown in the text boxes.

D. *Overall Coverage vs Throughput Considerations*

In addition to network outage, another performance aspect to be considered is the average user throughput for the different deployment alternatives. This can be seen as a measure of the overall improvements in network capacity. Table IV presents three different deployment solutions that achieve the required outage value of around 10 %. It can be inferred that the out-band pico-only scenario gives the worst average user throughput, with around 3 picos deployed per macro sector. Although 63 % of the users are offloaded to picos, the 10 MHz-bandwidth is shared amongst a large number of users, and it was shown that some of those are also in outage.

TABLE III. ISO-OUTAGE SCENARIOS WITH AVERAGE USER THROUGHPUT

Deployment Options	Nr Pico	Nr. Femto	User Outage	Off-loaded Users	Avg. UE TP
Pico-only Out-Band	35	-	9.3 %	63 %	2.08 Mbps
Femto-only Out-Band	-	500	12.3 %	51 %	**10.1** Mbps
Orthogonal Joint Femto-Pico	40	300	9.7 %	**72 %**	8.9 Mbps

When OSG femtos are deployed on a dedicated channel, the users experience the best average throughput, with a throughput gain of 5 times over the pico-only deployment. The femto cells are not overloaded and do not serve users in outage. This renders it possible to fully exploit the resources available at the femto cell, well beyond the ones needed to achieve the minimum data rate. The femto density needed to fulfill the outage requirement is in the order of 14 times higher than the one obtained with the pico-only deployment, i.e. 393 femtos/km^2.

The hybrid deployment of picos and femtos on dedicated bands gives the highest percentage of offloaded users towards the small cells, due to better SINR conditions experienced at both pico and femto layers. Besides deploying 40 picos, the required femto density is 236 femtos/km^2. The average user throughput is only 10 % less than the best one achieved with dense femto-only deployment, and this is potentially obtained at a lower cost as macro cells are not deployed at 2.6 GHz. Therefore, the hybrid femto-pico deployment turns to be a good trade-off between the required base station density and achieved performance.

V. CONCLUSIONS AND OUTLOOK

This study investigates and compares the LTE downlink performance of several heterogeneous deployment schemes in a realistic high-traffic metropolitan Hot-Zone scenario, using real 3-D building information and geo-location based spatial traffic distribution. By assuming a traffic growth by a factor of 50, and a minimum required user data rate of 1 Mbps, 43 % of the users are found to be in outage for the assumed dual-band macro-only deployment. Furthermore, it is evaluated that 70 % of the outage users are located indoor. To effectively decrease the outage level to the 10%-target, small cells are to be deployed on dedicated channels that are not interfering with the macro layer. A pico-only deployment with 3 outdoor picos per macro sector, or alternatively an indoor femto-only deployment with a density of 400 femtos/km^2, is sufficient to offload 50 % of the users and fulfill the outage target. Although the indoor femto-only scenario gives the best performance in terms of average user throughput, the hybrid deployment of outdoor picos and indoor femtos - with each layer transmitting on dedicated frequency resources - gives similar capacity improvements at a lower base station density and 70 % offloaded users.

As for potential future studies, the investigated deployment schemes can also be analyzed in terms of Total Cost of Ownership (TCO) to fully understand the viability of the investigated solutions and compare them with other deployment options, such as WiFi. Moreover, advanced traffic steering policies, power control and interference cancellation schemes could be investigated to evaluate performance gains in the co-channel deployment case under the same traffic assumptions.

REFERENCES

[1] Damnjanovic, A.; Montojo, J.;et al. “A survey on 3GPP heterogeneous networks” Wireless Communications, IEEE Vol.18 ,2011, Issue 3, pp. 1-21

[2] Kolding, T.; Ochal, P.;et al. “Impact of Carrier Configuration and Allocation Scheme on 3G Femtocell Offload Effect”, ”, *Proc. IEEE 73rd Veh. Tech. Conf.*, May 2011, pp.1-5.

[3] Wang, Y.; Pedersen K.I.; “ Performance Analysis of Enhanced Inter-cell Interference Coordination in LTE-Advanced Heterogeneous Networks”, *Proc. IEEE 75th Veh. Tech. Conf.*, May 2012 (Accepted).

[4] Hiltunen, K.; “Comparison of Different Network Densification Alternatives from the LTE Downlink”, *Proc. IEEE 74th Veh. Tech. Conf.*, September 2011.

[5] Eraldo Damosso, Luis M. Correia (ed), “Digital Mobile Radio Towards Future Generation Systems,” COST 231 Final Report.

[6] 3GPP TR 36.814, “Further Advancements for E-UTRA, Physical LayerAspects,” version 9.0.0, March 2010.

[7] Liang Hu; Kovacs, I.Z.; Mogensen, P.; Klein, O.; Stormer, W.; “Optimal New Site Deployment Algorithm for Heterogeneous Cellular Networks”, *Proc. IEEE 74th Veh. Tech. Conf.*, September 2011.

[8] Liang Hu; Coletti, C.; Nguyen, H.; et al. “How much can Wi-Fi offload? - A Large-scale Dense-urban Indoor Deployment Study” *Proc. IEEE 75th Veh. Tech. Conf.*, May 2012 (Accepted).

[9] Coletti C.; Mogensen P.E.; Irmer R.; “Deployment of LTE In-Band Relay and Micro Base Stations in a Realistic Metropolitan Scenario”, *Proc. IEEE 74th Veh. Tech. Conf.*, September 2011.

[10] Kovacs, I.Z.; Mogensen, P.; Christensen, B.; Jarvela, R.: “Mobile Broadband Traffic Forecast Modeling for Network Evolution Studies”. *Proc. IEEE 74th Veh. Tech. Conf.*, September 2011.